Polarimetric Characteristics of Specular and Dense Multipath Components in an Industrial Hall

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***Abstract*—This contribution analyzes the cross-polarization discrimination and the co-polar ratio of channel sounding data in a large industrial hall. The polarimetric parameters are calculated for the complete channels including measurement antennas, and for the specular and dense multipath components estimated with the RiMAX algorithm. The main observation is that horizontally polarized waves in the specular and dense part of the channel undergo an equal amount of depolarization while the depolarization of vertically polarized waves seems to be more pronounced in the dense part. A physical explanation for this observation based on the hall's high ceiling is given.**

***Index Terms*—radio channel modeling, propagation parameter estimation, polarization.**

I. Introduction

Over the course of the last decade, the modeling of the radio channel has undergone an important change. Before that, the radio channel was commonly modeled as a collection of Specular Multipath Components (SMC) that each have well-defined *discrete* locations in the angular and time-delay domains. However, it is also widely recognized that part of the radio channel appears to be *continuous* across these domains. This part is put under the umbrella of Dense Multipath Components (DMC) [1]. Among other sources, DMC originates from distributed diffuse scattering on electrically small objects.

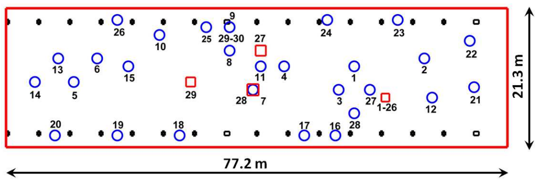
In this contribution, we analyze the polarization properties of the SMC and DMC in a large industrial hall. The analysis is based on frequency-domain channel sounding experiments. The polarization characteristics of the radio channel are quantified and analyzed by means of the cross-polarization discrimination (XPD) and co-polar ratio (CPR) parameters.

II. Materials and Methods

The propagation environment under consideration is a large industrial hall located in Zwijnaarde, Belgium. The hall has dimensions 21.3 x 77.2 x 12.2 m^3. The main inventory consists of large metallic machinery used for conducting experiments on concrete structures. The dominant building material for walls, floor, and ceiling is concrete. Fig. 1(a) presents a view of the industrial hall.

Multidimensional channel sounding measurements were performed in the industrial hall. A 4-port vector network analyzer was used to probe the full polarimetric radio channel in a 22 MHz bandwidth centered around 1.3 GHz (M_F = 1601 frequency points). At both link ends, a virtual uniform circular antenna array was created by a dual-polarized square patch antenna mounted on an automated rotating arm installed at 1.60 m above ground level. M_T = M_R = 12 is the number of array elements at the Tx and Rx, respectively. In total 29 Tx-Rx links were measured, shown in Fig. 1(b). The locations of the Tx and Rx are shown as blue circles and red squares, respectively. Tx and Rx locations sharing the same number form a Tx-Rx measurement pair. The shadowing conditions for the links were either Line-Of-Sight (LOS) or Obstructed Line-Of-Sight (OLOS).

(a) Industrial hall



(b) Tx (circles) - Rx (squares) measurement pairs

Fig. 1. Measurement environment

The RiMAX maximum-likelihood estimator is used to extract the full-polarimetric SMC and DMC from the channel sounding data [1]. The de-embedding of the full polarimetric complex radiation patterns of the measurement antennas is based on the effective aperture distribution function in [2].

III. Results and Discussion

A. XPD/CPR of measured channel gains

The XPD and CPR values are calculated directly from the measured polarimetric channels h_{XY} which include the SMC/DMC contribution and antenna effects. The expectation $\mathbb{E}\{\cdot\}$ is taken over the $M_T M_R$ spatial subchannels to remove small-scale fading. X and Y denote the transmit and receive polarization, respectively (either H or V). The XPD for H and V, and the CPR for a certain Tx-Rx link are given by:

$$XPD_H = 10\log_{10}\left(\mathbb{E}\left\{\frac{|h_{HH}|^2}{|h_{HV}|^2}\right\}\right) \tag{1}$$

$$XPD_V = 10\log_{10}\left(\mathbb{E}\left\{\frac{|h_{VV}|^2}{|h_{VH}|^2}\right\}\right) \tag{2}$$

$$CPR = 10\log_{10}\left(\mathbb{E}\left\{\frac{|h_{HH}|^2}{|h_{VV}|^2}\right\}\right) \tag{3}$$

Table I presents the measured XPD and CPR values averaged over the LOS and OLOS Tx-Rx links separately. There appears to be slightly more depolarization for V than for H. However, this could be attributed to the 1 dB gain difference between the H and V ports of our patch antennas instead of to the radio channel (also notice the CPR values are close to 1 dB).

	XPD_H [dB]	XPD_V [dB]	CPR [dB]
LOS	12.2	11.05	0.97
OLOS	8.48	7.58	0.5

TABLE I
MEAN OF THE MEASURED XPDS AND CPRS

B. XPD/CPR of SMC and DMC

In this section, the SMC and DMC are de-embedded from the measured channels while taking the radiation patterns of the measurement antennas into account. The SMC XPD and CPR are calculated per path p of each Tx-Rx link. The average number of paths per Tx-Rx links is around 200. The per-path XPD and CPR are given by (γ^p_{XY} denotes the path's estimated complex amplitude):

$$XPD^p_H = 10\log_{10}\left(\frac{|\gamma^p_{HH}|^2}{|\gamma^p_{HV}|^2}\right) \tag{4}$$

$$XPD^p_V = 10\log_{10}\left(\frac{|\gamma^p_{VV}|^2}{|\gamma^p_{VH}|^2}\right) \tag{5}$$

$$CPR^p = 10\log_{10}\left(\frac{|\gamma^p_{HH}|^2}{|\gamma^p_{VV}|^2}\right) \tag{6}$$

Table II presents the mean and deviation of the per-path XPDs and CPRs. For this, all paths were grouped according to whether they originated from a LOS or an OLOS link. It is found that the per-path XPDs and CPRs are well-described by a Gaussian distribution. The results demonstrate that the polarimetric characteristics are rather different between V and H polarized paths: H polarized paths suffer more from depolarization than V polarized paths (see e.g., the negative values of the mean CPR). This behavior is not observed in the measured channels (Table I).

This behavior of the SMC may be explained as follows. For specular paths with low elevation (i.e., nearly parallel to azimuthal plane), the H polarization will undergo more depolarization than the V polarization because of the Brewster angle effect [3]. Conversely, for specular paths with high elevation, the Brewster angle effect will cause V polarized paths to depolarize more than H polarized paths. The paths with high elevation in the latter case are commonly those that reflect off the high ceiling. These paths are characterized by a large path length and thus low power. One can thus argue that the XPD for V polarized paths is generally higher than for H polarized paths because V depolarization occurs more frequently for insignificant low-power paths. This leads us to conclude that buildings with high ceilings, such as industrial halls, favor V polarization over H polarization for the SMC.

	XPD^p_H [dB]		XPD^p_V [dB]		CPR^p [dB]	
	mean	std	mean	std	mean	std
LOS	7.41	3.25	11.6	2.94	-4.65	3.24
OLOS	4.66	3.24	10.11	2.96	-6.15	3.25

TABLE II
MEAN AND STANDARD DEVIATION OF THE SMC XPDS AND CPRS

Table III presents the average XPDs of the DMC for the LOS and OLOS links separately. In contrast to the SMC, the DMC depolarization is nearly the same for LOS/OLOS and H/V polarization. The SMC and DMC average XPD values for H are within 2.2 dB from each other which may indicate that they undergo similar interactions with the environment (i.e., reflect largely of the same objects with similar incident angles). In contrast, a larger average depolarization is observed for V polarized DMC than for V polarized SMC. A possible explanation is that the DMC contains a lot of the high-elevation low-power paths that are largely absent from the SMC (cf. previous paragraph). The depolarization of V polarized waves is thus predominantly effectuated by the DMC process.

	XPD_H [dB]	XPD_V [dB]
LOS	5.29	5.17
OLOS	6.84	4.16

TABLE III
MEAN OF THE DMC XPDS

IV. CONCLUSION

This contribution presented empirically obtained values of the cross-polarization discrimination and the co-polar ratio in a large industrial hall. The main finding is that horizontally and vertically polarized waves appear to undergo an amount of depolarization that is dependent on whether they belong to the specular or the dense part of the channel.

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